THE EUROPEAN LARGE AREA ISO SURVEY: ELAIS

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ABSTRACT

The European Large Area *ISO* Survey (ELAIS) has surveyed $\sim$ 12 square degrees of the sky at 15μm and 90μm and subsets of this area at 6.75μm and 175μm using the Infrared Space Observatory (*ISO*). This project was the largest single open time programme executed by *ISO*, taking 375 hours of data. A preliminary catalogue of more than 1000 galaxies has been produced. In this paper we describe the goals of the project, describe the follow-up programmes that are in progress, and present some first scientific results including a provisional number count analysis at 15 and 90μm .

Key words: ISO; infrared astronomy; surveys; starburst galaxies; AGN.

1. INTRODUCTION

The European Large Area *ISO* Survey (ELAIS) is a collaboration involving 19 European institutes (in addition to the authors and others at their institutes the following people and others at their institutes are involved I. Gonzalez-Serrano, E. Kontizas, R. Mandolesi, J. Masegosa, K. Mattila, H. Norgaard-Nielsen, M. Ward) and is the largest open time project being undertaken by *ISO*.

In this paper we describe some of the key scientific goals of ELAIS and give a brief description of the survey, comparing it with other ISO surveys. We give a preliminary discussion of the 15 and 90 μm source-counts and describe the follow-up programme now under way at a wide range of wavelengths, giving some first scientific results.

2. KEY SCIENTIFIC GOALS

In this section we highlight some of the principal scientific motivations for this programme, though naturally there are many other goals which we do not have space to discuss.

- The main extra-galactic population detected by IRAS was galaxies with high rates of star formation. These objects are now known to evolve with a strength comparable to AGN. The sensitivity of *ISO* allow us to detect these objects at much higher redshifts and thus obtain greater understanding of the cosmological evolution of star formation. This is directly complementary to studies of star-formation history in the optical and UV. Comparison of the star-formation rates determined in the FIR with that determined from the UV will give a direct estimate of the importance of dust obscuration, vitally important for models of cosmic evolution.
- If elliptical galaxies underwent a massive burst of star-formation between $2 < z < 5$, they would be observable in the far infrared and may look like IRAS F10214+4724. This survey will provide a powerful discrimination between such a top-down scenario and any hierarchical bottom-up merging model whose components are individually too faint to detect.
- Unified models of AGN suggest that the central engine is surrounded by a dusty torus. The mid and far infrared emission from the torus is much less sensitive to the viewing angle than the optical. Thus a mid and far infrared selected sample of AGN will place important constraints on unification schemes.
- IRAS uncovered a population with enormous far infrared luminosities, $L_{\rm FIR} > 10^{12} L_{\odot}$. While many of these objects appear to contain an AGN it is argued that star formation could provide most of the energy. Interestingly, most of these objects appear to be in interacting systems, suggesting a triggering mechanism. Exploration of

this population to higher redshift will have particular significance for models of AGN/galaxy evolution.

3. THE ELAIS SURVEY

The *ISO* observations began on 12th March 1996 and ended on 8th April 1998, shortly before the exhaustion of the Helium coolant. The total survey area covered in blank fields is 6, 11, 12, & 1 sq. deg. at 6.75, 15, 90 and 175 μm , and an additional 2 sq. deg. within the ELAIS survey areas has been surveyed at 175 μm by the FIRBACK team (Puget et al 1999). Table 1 specifies the main survey areas. A full description of the survey will be given by Oliver et al (1999).

As part of the follow-up programme described below, we have embarked on surveys of these same areas at X-ray, ultraviolet, visible, near infrared, submillimetre and radio wavelengths. Table 2 shows the wavelengths and areas covered (or planned to be covered in allocated observing time) across the whole electromagnetic spectrum. The surveys at 2-10 keV, U, K, 850 μm and 21 cm will be among the largest area surveys in these wavebands, to these sensitivities, being undertaken. Thus ELAIS has developed from its original concept as a survey at 15 and 90 μm into a powerful multiwavelength survey across the entire electromagnetic spectrum.

4. COMPARISON WITH OTHER *ISO* SURVEYS

ISO carried out a variety of surveys exploring the available parameter space of depth and area (cf the review by Oliver (1998)). Table 3 summarizes the main ISO extra-galactic blank-field surveys. It is clear that information will be available at a wide range of ISO wavelengths, and to a wide range of sensitivities, and that together these surveys will provide a powerful probe of the infrared sky. The ELAIS survey will play a key role because of its large area and the numbers of sources detected (see Table 2 for numbers found in our Quick-Look Analysis).

5. PRELIMINARY NUMBER COUNTS

Source catalogues have been extracted from the ELAIS data at all wavelengths and a preliminary source count analyses have been performed at 15 and 90 μm . The 15 μm results are shown in Figure 1, where we have included results from our HDF-N survey (Oliver et al 1997, Aussel et al 1998), from the ISO Deep survey in the Lockman hole (ref) and extrapolated from IRAS 12 μm counts (Verma 1999). The models shown are from Pearson and Rowan-Robinson (1996) and agree well with the data. Similar agreement is found for the models of Franceschini et al (1997). As can been seen these counts confirm the strong evolution detected in the *ISO HDF* analysis (Oliver et al 1997). A more detailed analysis of the 15 μm counts will be presented shortly (Serjeant et al 1999).

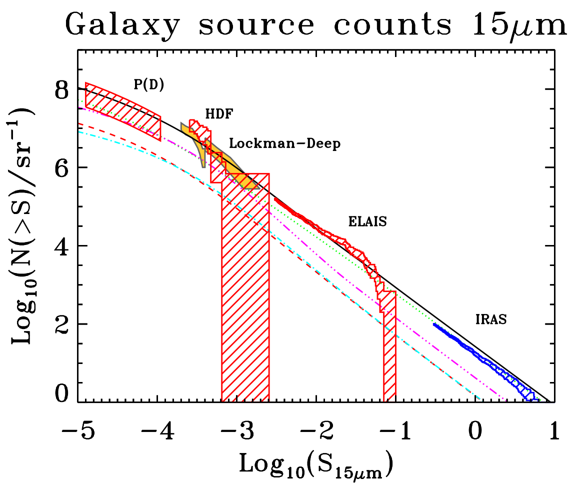

Figure 1. Preliminary 15 μm integral source counts from the ELAIS survey (Serjeant et al 1999), together with counts from *ISO HDF* (Oliver et al 1997, hatched, Aussel et al 1998, shaded), and CAM Deep survey (Elbaz et al 1998, shaded), with *IRAS* 12 μm counts (hatched) at bright end, (*IRAS* data shifted to 15 μm using cirrus spectrum (Verma 1999)). Models are from Pearson and Rowan-Robinson (1996): all components solid; spiral galaxies dotted; star-bursts dash-dot-dot-dot; AGN-dash. Faint end constraints (hatched) come from the *ISO HDF* $P(D)$ analysis.

The counts at 90 μm (Fig 2) are extremely preliminary, since there are still major uncertainties in the calibration and there is so far no detailed correction for incompleteness due to the variable effects of cosmic rays. However they show reasonable consistency at the bright end with counts at 90 μm interpolated from IRAS 60 and 100 μm data and demonstrate that we should be reasonably complete at least to 100 mJy. A more detailed discussion of the 90 μm counts will be given by Efstathiou et al (1999).

Results from our northern and southern 21 cm surveys have already been published (Ciliegi et al 1999, Gruppioni et al 1999) and show good consistency with earlier sub-mJy radio surveys. These radio surveys represent a very substantial expansion of the area of the sky surveyed to sub-mJy sensitivities and the follow-up of these radio surveys will be a very interesting project in its own right.

6. FOLLOW-UP

An extensive follow-up programme is being undertaken, including measurements at all wavelengths from X-ray to radio (Tables 2 and 4). This programme will provide essential information for identifying the types of objects detected in the infrared, their luminosities, energy budgets and other detailed properties. As well as studying the properties of the

Table 1. Summary of ELAIS Survey Areas. These areas were selected primarily for having low Cirrus contamination, specifically $I_{100} < 1.5$MJy/sr from the IRAS maps of Rowan-Robinson *et al.* (1991). For N1-3, S1 and all X areas we also restricted ourselves to regions of high visibility > 25% over the mission lifetime. For low Zodiacal background we required $|\beta| > 40$ and to avoid saturation of the CAM detectors we had to avoid any bright IRAS 12μm sources. 6 additional small ($0.3^\circ \times 0.3^\circ$) rasters (X1-6) were centred on well studied areas of the sky or high-z objects

Name	Nominal Coordinates J2000		M /°	N /°	ROLL /°	$\langle I_{100} \rangle$ /MJysr^{-1}
N1	$16^h10^m01^s$	$+54^\circ30'36''$	2.0	1.3	20	1.2
N2	$16^h36^m58^s$	$+41^\circ15'43''$	2.0	1.3	30	1.1
N3	$14^h29^m06^s$	$+33^\circ06'00''$	2.0	1.3	330	0.9
S1	$00^h34^m44^s$	$-43^\circ28'12''$	2.0	2.0	20	1.1
S2	$05^h02^m24^s$	$-30^\circ35'55''$	0.3	0.3	290	1.1

Table 2. Field Surveys within the ELAIS regions, the vast majority carried out as part of the ELAIS collaboration.

Band	2-10keV	U	B, V, I	R	H/K	6.7	15	90	175	850	21cm
Area (sq degs)	0.15	6	1	13	1	6	11	12	3	0.1	8.2
Depth	1×10^{-14}	22.5	23	23.5	19.5	1	3	100	100	8	0.1-0.4
Units	CGI	mag	mag	mag	mag	mJy	mJy	mJy	mJy	mJy	mJy
Galaxies		30000			3000	1104	1618	390	100		1448
Stars		15000									

Table 3. Field Surveys with *ISO*

Survey Name	[e.g. ref]	Wavelength /μm	Integration /s	Area /sqdeg
PHT Serendipity Survey	Bogun et al 96	175	0.5	7000
CAM Parallel Mode	Siebenmorgen et al 96	7	150	33
ELAIS		7,15,90,175	40, 40, 24, 128	6, 11, 12,1
CAM Shallow	Elbaz et al 98	15	180	1.3
FIR Back	Puget et al 99	175	256, 128	1, 3
IR Back	Mattila et al 99	90, 135,180	23, 27, 27	1, 1, 1
SA 57	Norgaard-Niielson et al 97	60, 90	150, 50	0.42,0.42
CAM Deep	Elbaz et al 98	7, 15, 90	800, 990, 144	0.28, 0.28, 0.28
Comet fields	Clements et al 99	12	302	0.11
CFRS	Hammer and Flores 98	7,15,60,90	720, 1000, 3000,3000	0.067
CAM Ultra-Deep	Elbaz et al 98	7	3520	0.013
ISOHDF South	Oliver et al 99b	7, 15	$> 6400, > 6400$	4.7e-3, 4.7e-3
Deep SSA13	Taniguchi et al 97	7	34000	2.5e-3
Deep Lockman	Kawara et al 98	7, 90, 175	44640, 48, 128	2.5e-3, 1.2 , 1
ISOHDF North	Serjeant et al 97	7, 15	12800, 6400	1.4e-3, 4.2e-3

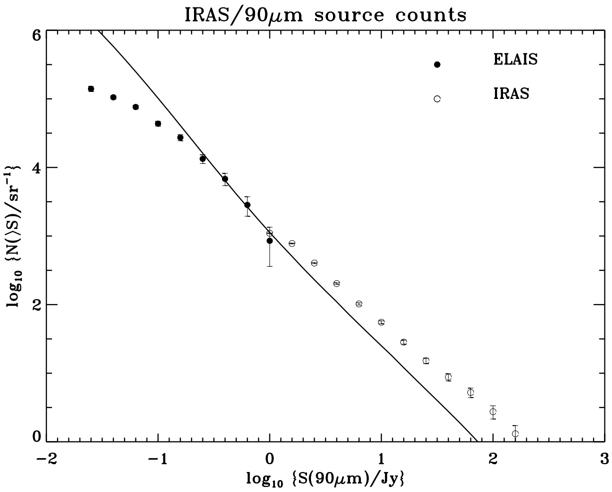

Figure 2. Preliminary 90 μm integral source counts from the ELAIS survey (filled circles), together with counts interpolated from *IRAS* 60 and 100 μm data (open circles) (Verma 1999). Model is from Rowan-Robinson (1999).

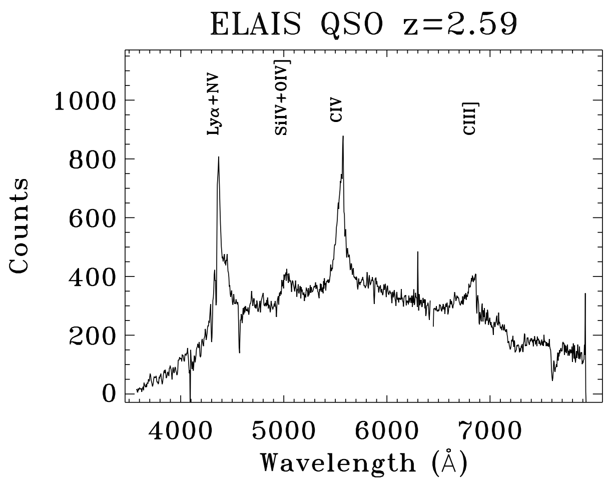

Figure 3. Spectrum of a z=2.59 QSO associated with an ELAIS 15 μm source, taken with the 2dF on the AAT (Gruppioni et al 1999).

objects detected by *ISO* a number of the follow-up surveys will provide independent source lists which will be extremely valuable in their own right, not least because we can investigate why some objects emit in the infrared and others do not. As we emphasized above ELAIS has become a deep multi-wavelength survey of these 12 sq degrees of sky, which will have impacts on a wide range of extragalactic astrophysics. The wealth of multi-wavelength information will make ELAIS areas a natural focus for future surveys, for example with WIRE, SIRTF, XMM and FIRST.

Preliminary optical identifications have already been made for several hundred 15 and 90 μm and 21 cm sources and these have been the subject of several spectroscopic runs (see Table 4). Results from spectroscopy of 90 μm galaxies with R $<$ 18 in the south using FLAIR and the ESO/Danish 1.5m telescope will be published shortly (Linden et al 1999). As expected the galaxies tend to be normal spirals or starbursts. We will also be reporting the first results from spectroscopy of 15 μm and 21 cm galaxies using 2dF and the ESO 3.6m and NTT telescopes (Gruppioni et al 1999, La Franca et al 1999). Figure 3 shows the spectrum of a z=2.59 quasar found in our first 2dF run. Taking into account those galaxies which are too faint for their spectra to be classifiable, about 20-40 % of the 15 μm galaxies for which we have spectra so far are AGN (QSO, Sey 1, Sey 2 or NELG), broadly consistent with expectations of the models of Pearson and Rowan-Robinson (1996) and Franceschini et al (1998).

In conclusion it is clear that the ELAIS project will not only meet its original scientific goals, but will also provide the basis for a series of powerful multiwavelength surveys over the next decade.

7. ACKNOWLEDGEMENTS

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Table 4. ELAIS Follow-up Programme Summary

Telescope	shifts/nights	Projects
AXAF	150ks	X-ray Survey in N1, N2
ESO 3.6m	3	Optical Imaging
		Optical Sepctroscopy
ESO NTT	9	NIR Photometry
		Optical Spectroscopy
ESO 2.2m	13	NIR Photometry
ESO/Dan. 1.5m	35	Optical Survey
		Optical Photometry
		Optical Spectroscopy
AAT	2	Optical Spectroscopy (2dF)
		NIR Spectroscopy
INT	13	Optical Survey
		NIR Survey
CFHT	1	Integral Field Spectroscopy
Calar Alto 3.6m	8	Optical Spectroscopy
		NIR Photometry
Calar Alto 2.2m	2	Optical Spectroscopy
UK Schmidt	2	Optical Spectroscopy (FLAIR)
Mt.Hopkins	12	NIR Photometry
ITRF	5	NIR Photometry
IAC 0.8m	28	Optical Photometry
ESA OGS 1.m	4	Optical photometry
ATNF CA	10	21 cm Survey
VLA	6	21 cm Survey

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